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THE MAIN METHODS FOR PRESSURE MOLDING OF TECHNICAL CERAMIC PRODUCTS

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The long practical experience of the author in the field of molding of ceramic articles is summarized and can be used by specialists in the development of technological processes in ceramic production at the enterprises and in upgrading the current technological processes to improve the product quality.

Technical ceramics used in electronics and electrical engineering have to meet especially strict requirements imposed on mechanical strength and maintaining strength at high service temperature, thermal resistance, and electrophysical properties. The products have to possess high vacuum density even with a small wall thickness (0.25 – 0.30 mm) and the capacity for forming vacuum compounds with metals.

Such articles are mostly molded of pure oxide non-plastic materials. These materials cannot be plastically molded; therefore, they are produced by hot injection molding and pressure molding.

The first method is applied only to articles of small size and complex configuration. The main method for producing technical ceramic articles is pressure molding [1, 2].

The following methods are distinguished in molding technology, depending on the type of pressure applied to the compressed material: static, vibration, impact, dynamic, hydrodynamic, electric pulse, explosion, hydrostatic, and quasi-isostatic molding.

The most common is static molding, i.e., compression in standard metal molds, when pressure is uniaxially applied to the material (Fig. 1). Static molding uses closed molds. The content of the technological binder in molding powder usually ranges in the limits of 5 – 6%, and only in certain cases reaches 10%. The average molding pressure for plastic materials of the porcelain mixture type is 25 MPa, for ultraporcelain 50 MPa, and for non-plastic materials it varies from 100 to 200 – 300 MPa.

This method is used to mold articles using a wide range of materials. Static molding is the only method for making facing tiles and floor tiles. It is highly efficient and economical. Its use makes it possible to obtain high precision and good surface purity, as well as fully mechanize and automate the production process.

Static molding was successfully used by us in molding a wide range of small ceramic parts for metal casing. To make metal ceramic cases for integral circuits, a mechanized line for molding ceramic parts was developed and put into production. Its capacity is 20 million pieces per year and it uses M-292 automatic molding machines. The machine capacity is 17,000 parts per shift.

However, in spite of significant advantages, this method has a serious drawback, since it is suitable only for articles of low height. Otherwise, the density of molded articles is inhomogeneous. The further from the punch, the lower the density of the articles, due to the pressure loss caused by overcoming the external friction of the mixture against the mold walls. In this case to avoid inhomogeneity one should use machines with additional bottom compression, or in their absence to use the floating matrix method, i.e., applying pressure from both ends of the molded article.

Static molding is acceptable for molding articles with a height : diameter ratio equal to 1 : 1 [3]. However, the long

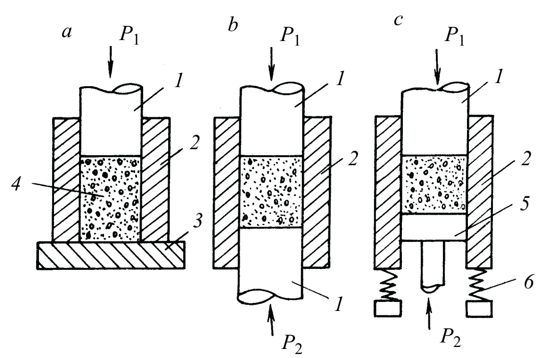

Fig. 1. Scheme of static (uniaxial) molding developed by one mobile punch (*a*), two punches moving toward each other (*b*), the upper punch and the mobile floating matrix (*c*): *1*) mobile punch; *2*) matrix; *3*) immobile punch; *4*) molded mixture; *5*) floating matrix; *6*) springs supporting the matrix.

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practical experience of the author in static molding of various ceramic materials (porcelain, steatite, ultraporcelain, high-alumina and aluminum-oxide materials, glass ceramics, etc.) demonstrated that this ratio is applicable to articles of height 25 – 30 mm. In molding articles out of non-plastic materials, it is impossible to accomplish homogeneous density in articles more than 30 mm high by one-side pressing; whereas using two-side compression, it is possible to mold articles 50 – 60 mm high. For plastic ceramics the height of the articles is 50 – 60% higher. However, it should be noted that disks 8 – 10 mm high and 200 mm in diameter used in electronic industry could not be produced by static molding, due to the nonuniform density in the diameter direction. This problem was solved in producing these articles by quasi-isostatic molding.

A variant of the static molding method is molding in open molds, known as stamping, which is commonly used in the production of low-voltage insulators and electrical installation products. These articles amount to about 40% of electrical engineering ceramics [4]. Many industrial enterprises in our country are engaged in this production.

The content of provisional technological binder in stamping is 13 – 18%, and the molding pressure, depending on the size of the articles, ranges from 7.5 to 12.5 MPa.

A high content of provisional technological binder in developing molding pressure provides for good mobility of the molding powder, which makes it possible to obtain samples with relatively uniform volume density. Excessive molding powder poured into the mold flows out due to its high fluidity, when the punch contacts the matrix or via the lateral openings in the matrix.

Molding powder ensures good moldability on automatic and semi-automatic machines in single-cavity and multi-cavity molds. Such articles are usually made on mechanic presses, which have high efficiency and are easy to operate. As a rule, such presses are developed and produced directly at ceramic factories. This molding method is at present the most promising way for molding low-voltage and electrical porcelain parts.

A variety of static molding is differential molding, which is used for molding articles of complex configuration with protrusions and hollows or with walls of different thickness. When the thickness of the article changes, each part is molded by a different punch. However, such molds have a complicated design, and its manufacture in metal and its operation involves various difficulties. Therefore, differential molding is applicable only to single kinds of ceramics, on which especially strict requirements for precision and density are imposed.

In addition to static molding, ceramic works currently use vibration molding. In this method the compaction of molded material is implemented through removing the air phase from the molding powder. This is determined by the fact that under the effect of vibration pulses, individual velocities and accelerations are imparted to powder particles, and consequently, the internal friction forces decrease, the arch-shaped formations disintegrate, and conditions for more compact packing of the molding powder particles are created [5].

The molding pressure developed in using this method is lower by 1 – 2 order of magnitude than in the static molding of similar articles. However, this method has not become common due to its several shortcomings, the principal of which is a substantial noise level, which requires installation of soundproof facilities and vibration-proof foundations; machinery parts and units in this method should have increased strength.

The studies of aluminum oxide material VK 94-1 involving molding of rings 300 mm in diameter and 130 mm were performed by us together with the Institute of Physical Chemistry of the Academy of Sciences of the USSR and showed the difficulty of maintaining stable molding conditions. To produce high-density articles, an optimum combination of vibration parameters is essential: frequency, amplitude, and specific molding pressure. In molding such articles, the selected molding conditions significantly varied depending on the variations in the technological binder content, the granulometric composition and the shape of powder particles, the method of molding powder preparation, and its aging duration. Therefore, it was impossible to develop a process technology for the specified articles [6].

In molding laboratory samples (discs 30 and 40 mm in diameter made of the same material), it was established that high quality of articles can be ensured with a significant decrease in the specific molding pressure, by approximately 2 orders of magnitude. However, molding of disks about 60 mm in diameter required a substantial modification of the molding parameters. That is why vibration at ceramic factories is mostly used for preliminary compaction of powder before molding, which contributes to the improvement of the product quality.

The new molding methods (impact, dynamic, hydrodynamic, electric pulse, and explosion molding) are not used in serial production due to their complexity and the high cost of machinery.

The best investigated methods are isostatic and hydrostatic (using liquid as the molding medium) molding.

The hydrostatic molding method is the most promising for molding articles with a relatively substantial height, which cannot be produced by other methods currently used in production. The resulting articles are characterized by uniform density, owing to which their shrinkage in subsequent sintering is uniform in volume and less than in articles molded in steel molds.

The hydrostatic molding method makes it possible to obtain articles with a high ratio of height to diameter (height up to 2 – 3 m) and a substantial weight (up to 500 kg). The height and diameter of molded articles are determined by the possibility of making hydrostats of respective sizes and in principle can be indefinitely large.

The VNIIÉK Institute carried out a number of studies in hydrostatic molding of ceramic articles. Hydrostatic molding

plants for laboratory purposes with molding pressure 15, 25, and 50 MPa were developed, as well as experimental prototype and industrial plants (200 MPa). A more sophisticated hydrostatic molding plant was equipped with automatic loading of molding powder, automatic lift of the molding chamber lid, and removal of articles using hydraulic devices.

The hydrostatic plants made it possible to develop a hydrostatic molding technology for several types of bushing insulators, including lock couplings 720 mm high. This technology has been implemented in the serial production. A technology has been developed for producing thin-walled cones of several standard sizes (up to 467 mm high, base diameter up to 320 mm, and 5 mm wall thickness) of high-alumina material. A molded article is extracted from the hydrostat using vacuum.

Production technology has been developed for making pipes 220 mm in diameter and 600 mm long, insulators IP-617 and IP-618, pot condensers, and traction. Another study involved molding articles of complex shape, i.e., wing insulators, each having several wings with overhang up to 60 mm (Fig. 2). The fundamental development of techniques and structural elements of the equipment provided for uniform consolidation of powder both in the insulator body and in the wings, as well as free removal of articles from the hydrostat.

Insulators were molded of various ceramic materials: porcelain, steatite, ultraporcelain UF-46, high-alumina material GB-7, condenser mixtures, and glass ceramic material of grade IV-23.

The performed studies [7] indicated that this method makes it possible to mold products using a wide range of materials, including non-plastic ones. However, along with important advantages, this method also has some disadvantages, which impedes the wide implementation of this technology in mass production:

– this method calls for large capital investments, since it requires a set of machinery: an expensive hydrostat of a complex structure made of special strong steels, vacuum pumps, a tank for molding liquid, a transport device for removing and inserting the hydrostat lid and for charging molding powder, a complex system of high-pressure pipelines, various measuring devices; furthermore, hydrostats can be produced only by specialized manufacturing companies;

– the machinery is energy- and metal-consuming, takes a lot of production space, and requires numerous operating personnel;

– domestically produced rubber shells have low service life: from 30 to 150 moldings, depending on the type of produced articles;

– hydrostatic equipment requires high skill of the operating personnel and is difficult to repair;

– hydrostatic molding has low efficiency;

– it is difficult to subject molding powder loaded in a hydrostat to vibration treatment, due to the large size of the hydrostat and the existence of connecting pipelines.

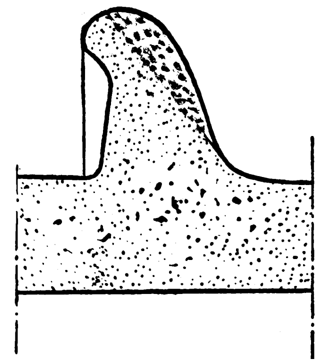

Fig. 2. Profile of insulator wing.

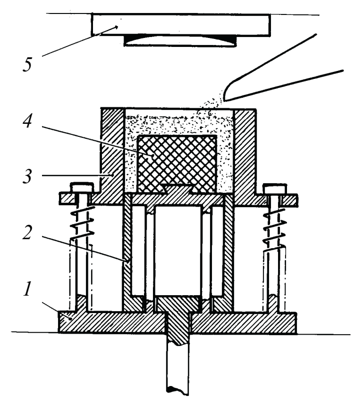

Fig. 3. Diagram of a mold for quasi-isostatic molding: *1*) body; *2*) pusher; *3*) matrix, *4*) elastic press-buffer; *5*) punch.

The above drawbacks and some other factors revealed in the development of hydrostatic molding technology for insulators motivated the search for a simpler, more accessible, and more economical method, which was quasi-isostatic molding.

The principle of quasi-isostatic molding consists in the fact that the medium transmitting uniform isostatic pressure is a solid elastic material, such as rubber, synthetic caoutchouc, and other similar elastomers, which isostatically transmit the applied pressure to the molded material, similarly to a high-viscosity liquid (quasiliquid) and ensure the production of articles with homogenous density by creating conditions for volume compression.

This molding process is implemented on standard hydraulic or mechanical presses manufactured by the domestic producers. Moreover, ceramic works are traditionally equipped with such presses. Molding is implemented in quasi-isostatic molds, which resemble the standard static molds in their design, installation method, and performance and can be produced at ceramic works (Fig. 3).

Due to the volume compression, pressure in quasi-isostatic molding is 30 – 50% lower than in the case of standard static molding.

A technology has been developed for making refractory saggers and shells from alundum material, chamotte, and

carborundum mixtures using the quasi-isostatic method and has been implemented at four ceramic works. Due to the volume compression, the quasi-isostatic molding technology ensures the high quality of saggers. The service turnover of the saggers amounted to 15 – 22 cycles, which is several times higher than that of saggers made by the standard static molding method.

Another technology implies making vacuum-tight rings 96, 180, 190, and 250 mm in diameter and up to 170 mm high. These rings are made from aluminum oxide material VK 94-1 and used in arc-suppressing chambers and other electronic devices. This technology is implemented at two production companies making serial products.

The high quality of articles made it possible to develop a number of domestic devices, whose characteristics significantly surpassed analogous foreign products. The yield of acceptable products at the factory using the technology of quasi-isostatic molding was at least 65%, and in some periods 80 – 81%, which is significantly higher than in hot injection molding.

In addition to that, a quasi-isostatic molding technology has been developed for making milling balls 20, 30, 40, 50, and 60 mm in diameter from aluminum oxide material VK 94-1, which ensures high physicomechanical parameters and wear resistance 3.5 times higher than the resistance of milling bodies made of the same material by hot injection molding. A new ceramic material has been developed for milling balls with wear resistance 0.03%. A technology for making tubes 10 mm in diameter and 160 mm high with 1.5 mm wall thickness has been developed, as well as rods 17 mm in diameter and 160 mm long. A technology for molding tiles $425 \times 425 \times 65$ mm and other products has been developed and experimentally tested.

Owing to the triaxial application of pressure, quasi-isostatic molding is the most perfect method for molding ceramic articles; it is a highly efficient process suitable for full mechanization and automation. At the same time, this method ensures good quality of the products. This molding method can be used for making articles from various powdered materials, including glass ceramics, glass, ferrite, metals., etc. However, the maximum size of the articles is determined by the distance between the worktable and the slide bar of the applied press.

The long practical experience has made it possible to classify the reasons for the emergence of particular types of defects in each molding method and to develop measures for the elimination of such defects.

The variety of molding methods in production of ceramic and refractory articles allows for selecting the most expedient technological process for a particular product range, taking into account the product configuration and size. In any molding method, the main factors determining the quality of molded articles are the properties of molding powders and the molding conditions.

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